RESOURCE ALLOCATION FOR COMBINED VOICE AND DATA USERS IN CELLULAR DS-CDMA SYSTEMS

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Certificate

This is to certify that the work contained in the thesis entitled "*Resource Allocation for Combined Voice and Data Users in Cellular DS-CDMA Systems*", by *Satyendra Kumar*, Roll No. 9910474 has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Although it is not possible to express in words the way my parents have been supporting me and encouraging all the way along, this acknowledgement would be incomplete with out mentioning about them This thesis is dedicated to my brother and sisters whose love and inspiration has always helped me in my pursuit for betterment

Finally, I thank Almighty for his blessings throughout this work.

Satyendra Kumar

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Abstract

We consider a packet data DS-CDMA system which supports multiple services. The services are partitioned into different traffic classes according to transmission rate and quality of service. An analytical method of allocating resources viz. power and processing gain to different classes of users in the presence of other cell interference and imperfect power control for both uplink and downlink is presented. We consider two models for data users: random and continuous. We maximize the throughput of data users by finding the optimal processing gain of data users for a given value of processing gain of voice users. The quality of service measures considered are: average delay for data traffic and bit error rate for voice traffic.

Chapter 1

Introduction

Personal wireless communication systems currently in use around the world are first and second generation (2G) systems. First generation systems consist of the analog mobile phones that offered only voice communications, like Advanced Mobile Phone System (AMPS) and Total Access Cellular System (TACS). Second generation systems offer digital voice and low to medium-rate data communications (e.g. upto 9.6 kb/s). Some of the main systems are Global System for Mobile Communications (GSM), Digital AMPS (DAMPS)/IS-136, Personal Digital Cellular (PDC), and CdmaOne/IS-95B (IS-95B is the latest version of IS-95). Third generation systems are in development and will offer multimedia capabilities and support for high bit rates (144 kb/s to 2 Mb/s).

The ITU TG8/1 has proposed the third generation mobile communication system named as IMT-2000 (International Mobile Telecommunications 2000) [16]. The goal of the IMT-2000's project is to provide a higher level of service and capabilities than existing levels within the 2G systems. However, in doing so they would like to have an evolution from 2G to 3G systems, so that the wireless infrastructure companies (operators) will not have to scrap their hard-earned and expensive equipment and radio frequency spectrum. The main technical objectives of IMT-2000 are:

- Minimum data rate of 144 kb/s for full coverage and vehicular mobility, and 384 kb/s for pedestrian mobility.

- 2 Mb/s data rate for limited coverage and limited mobility (e.g. indoor office).

- High spectrum efficiency (more users) compared to existing systems.

- High flexibility to introduce new services

- Support of packet mode services (e.g. The Internet)

ITU has taken some decisions regarding the air interface for IMT-2000. This essentially allows a single flexible standard with a choice of multiple access method which consists of FDD-CDMA and TDD-CDMA, where FDD and TDD stand for Frequency Division Duplex and Time Division Duplex respectively while CDMA stands for Code Division Multiple Access. It was felt that allowing this flexible choice within a single standard would give operators the chance to best address their specific regulatory, financial and customer needs. This standard would also allow coexistence and interoperability between 2G and IMT-2000 or 3G compliant systems. It is hoped that small, lightweight multi-mode multi-band terminals for inter-system roaming on a global scale will be available.

1.1 Current Scenario

Future wireless systems are required to support different classes of services such as voice, data, image, video etc. Direct Sequence (DS)-CDMA system which is currently used in second generation IS-95 system is a promising technique to support these services efficiently.

Each class of service has different requirements of transmission rate and quality of service (BER, delay etc.). There are many ways in which the transmission rate and performance associated with different classes can be controlled in multirate DS-CDMA systems. For example a particular transmission rate can be achieved by an appropriate choice of chip rate [1], processing gain [2], number of codes [3] and modulation scheme [4].

In addition to [5], [9]-[10] have also used power allocation to satisfy QoS requirement. In [5], data throughput has been maximized for given values of voice and data PG by varying voice and data power. While in [9] throughput is maximized by minimizing the sum of all transmit power by mobiles. Dynamic assignment of PG in a time-slotted CDMA model is studied in [10].

1.2 Motivation for Present Work

In this thesis the transmission rate and quality of service of different classes are optimized by selection of different processing gains (PG). All other variables (chip rate, number of code and modulation scheme) are fixed for all users. The PG is varied by changing symbol duration. Doubling PG doubles the symbol duration. For data users, increase in PG increases the throughput. This is because increasing PG increases the Signal to Interference plus Noise Ratio (SINR) and therefore decreases retransmission probability. Traffic characteristics (packet generation rate and packet length) and system parameter such as desired QoS are same for all users in each classes. However they may differ from class to class.

In DS-CDMA system, perfect power control is a very critical issue due to near-far problem. Several studies [7]-[8] have shown that system performance is severely affected due to imperfect power control. Imperfect power control issue has been considered in our analysis. The level of imperfection depends on several factors like power control algorithm, mobility and distribution of mobiles.

In multi-cell CDMA system, the QoS of users are significantly affected by the other-cell interference - the interference from mobiles controlled by other base stations. This issue has also been considered in our analysis. Distribution of mobiles in the cell significantly affects othercell interference. Sectorization also affects othercell interference which directly affects the capacity. In other words we can say throughput is a function of all these parameters.

Two traffic models considered in this thesis for data generation are 1) Random and 2) Continuous. Random model corresponds to bursty transmissionl and continuous model corresponds to long file transmission. It has been assumed that each user generates a sequence of fixed length packets. The reliability of data communication is guaranteed through error detection and retransmission (ARQ). User traffic is partitioned into different classes for example voice, low priority data, and high priority data. Each of which requires a particular transmission rate and QoS. We address the problem of maximization of throughput of data users for a given number of users in each class.

The model we consider in this paper differs from the models considered in other

references [5], [9] and [10] in one or more of the following ways 1) The data traffic model accounts for both burstiness and retransmission. 2) Throughput and delay is studied as a function of both optimal power and optimal PG 3) After transmission of data packet the NAK is received after some time so delay includes not only retransmission time and queueing time but also the additional time of buffering a packet for retransmission In this thesis data throughput has been maximized by varying the data processing as well as power of both voice and data users considering the effect of othercell interference and imperfect power control. Due to different modeling assumptions as outlined above results are different as compared to results presented in preceding references

1.3 Organization of Thesis

The outline of the thesis is as follows In next chapter, brief overview of cdma systems is presented followed by comparison of various multirate methods Then othercell interference for different traffic cases such as uniform distribution of users uniform distribution with hot spot in cells and circular sectorization of cells is done Chapter 3 contains model and analysis of resource allocation for given models for both the uplink as well as for the downlink Results are summarized for different models in Chapter 4

Chapter 2

Multirate Methods in DS-CDMA Systems

2.1 Introduction

In a DS-CDMA system the data to be transmitted is first multiplied by a pseudo random spreading sequence (code signal) which is unique for each user. The ratio of rate of spreading sequence (chip rate) to data rate is called Processing gain. As each user occupies the entire bandwidth, each user interferes with every other user in addition to the already present background noise. Hence the DS-CDMA system is an interference limited system. On base-to-mobile link (Downlink), a cell's common pilot can be used for the channel estimation and time synchronization. The users channel can also be orthogonalized. On the other hand it is not feasible to provide individual pilot channel in the mobile-to-base link (Uplink) in second generation CDMA systems. Since different users are located at different locations, it is difficult to establish orthogonality between them. However in the proposed third generation (3G) system there is a provision to incorporate pilot channel in the uplink where ever the data rate demands, for a particular user. To deal with unpredictable propagation loss condition (due to shadowing and fading of radio channel and user mobility), power control is needed.

2.2 Various methods of achieving multirate in DS-CDMA systems

There are many methods by which one can achieve different transmission rate for the different classes i.e by varying chip rate, processing gain, number of codes and modulation. Here brief overview of various methods is presented [4].

In multi chip-rate system PG is constant hence the bit rate governs the chip-rate. This means that users with different rates have different bandwidths and we can squeeze many such subsystems within the system bandwidth. It is found that this strategy is complicated because the receiver must be synchronized to its particular code rate and the system needs additional frequency planning due to unequal bandwidth spreading of different users.

In a variable processing gain system, different data rates can be easily generated by varying the PG without changing the chip rate, modulation scheme or coding. For high bit-rates the PG is low while for low bit rates PG is high. However at high bit rates due to low spreading gain protection against interference decreases. It may also be difficult to find orthogonal codes for all data rates in the downlink. Absence of orthogonal codes increases inter channel interference. Despite the problems caused by short PG for high bit rate services, the variable PG scheme is a potential solution for providing multirate services. Since the transmission is carried out only on one code, the complexity of receiver remains low.

In multi modulation multirate scheme, different data rates are achieved by using different modulation schemes. However multi-modulation system, where all users have the same symbol rate and PG, is not an optimal way to implement multi-rate systems. First of all it would be difficult to implement many data rates by only changing modulation. Further, if it is assumed that all the users have the same signal-to-noise ratio per bit the transmitted powers are different for different rates. As spreading code is same for different users near-far-effects will arise. If on the other hand all users transmit at the same power the performance of high data rate users will degrade because of the lower E_b/N_0. For BPSK and QPSK modulation everything works fine but for higher modulation schemes the energy per bit is so small that the bit error rate is high.

In a multi-code system it is possible to provide different bit-rates by allocating several constant bit-rate codes for the same user. Under the circumstances, number of different data rates that can be supported depends on the basic bit rate. The disadvantage of this solution is that more the bit rates needed, more complex will be the receiver structure. Since all codes have the same, quite high, PG the suppression of intra cell interference is good. The inter symbol interference received from one code in this case is much smaller as compared to the variable PG scheme for high bit rate transmission. However, interference is received from all the codes that are used for transmission. The overall inter symbol interference is approximately same both in multi code and in variable PG alternatives.

Which is the best scheme for multirate transmission depends not only on the performance but also on many other parameters. It seems that multi code and variable spreading gain methods are preferred to the multi modulation and multi chip rate schemes. But which one of these two is better, is a more difficult question. Multi code method can provide orthogonal codes in the downlink which is more difficult for the variable spreading gain method. On the other hand, variable spreading gain method works with one receiver. Hence to decrease the complexity of receiver in mobiles it is preffered to use variable spreading gain method on the downlink. In the multi code case as many receivers are needed as there are codes. However, these receivers can be simple because of the higher PG in each channel. In addition to the high complexity of the receiver another severe problem for the multi code method is the requirement of linear amplifier, especially in the uplink. In this thesis variable PG method has been analyzed in both uplink and downlink.

2.3 Multirate/Multi-QoS DS-CDMA by varying processing gain

The approach for providing multirate services with different QoS requirements in different classes in DS-CDMA is as follows. The chip rate, number of spreading codes and modulation are fixed for all the sources, and the data rate is determined by selecting the PG. Thus, all the sources are multiplexed onto the same wideband channel which

maximizes trunking efficiency

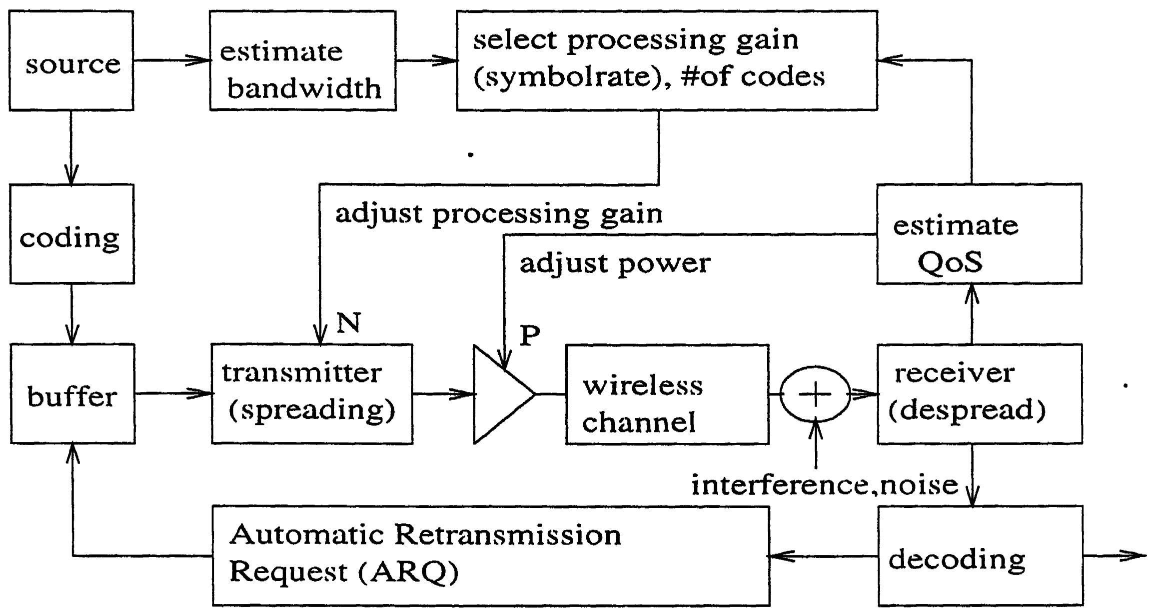

Figure 2.1: Parameter selection for multirate/multi-QoS DS-CDMA [5]

The block diagram which illustrates the selection of parameters, used to control the transmission rate and QoS is shown in Figure 2.1. Each source generates a sequence of fixed length packets of length L symbols, where L depends on the source. The packets generated by each source enter a buffer after error control coding. The buffer contents are then converted to a DS-CDMA signal at the symbol rate R/N, where R is the chip rate and N is PG, which is being varied. Since chip rate is fixed, PG determines the symbol duration. If the packet arrival rate is λ packets/s, then the PG should not be larger than $R/(\lambda L)$. Otherwise the rate at which packets arrive to buffer exceeds the rate at which the buffer is emptied (even without retransmissions).

At the receiver end, after despreading and decoding the received packet, receiver may request the transmitter to retransmit the packet if it contains errors. This is necessary for error sensitive users (data), but may be undesirable for voice users as they can tolerate error but not additional delay. The choice of PG (N) significantly affects packet delay as well as transmission rate. Of course, the performance can be improved by increasing the power P but this increases interference to other users. Here we examine performance (e.g. error rate and average delay) as a function of both N and P. Depending on the source characteristics, the choice of PG for a particular user can also affect the QoS of

the other types of users

2.4 Othercell interference

Power control attempts to equalize users received power at a given cell's base station, for all the users controlled by that base station But interference also arrives from the users controlled by other cell's base stations It is received at the given base station with lower power level, since soft hand off guarantees that a user is connected at all times through the best base station - the one with the least attenuation due to propagation loss The propagation loss is generally modeled as a product of the 4^{th} power of distance and a lognormal shadowing factor [15] Thus, for a user at a distance r from a base station attenuation is

$$\alpha(r, \xi) = r^4 10^{\xi/10} \qquad (2.1)$$

where ξ is a Gaussian random variable, with zero mean and standard deviation σ.

2.4.1 Uniform distribution of users

Assuming users are uniformly distributed in all cells Following the method of [6] if the interfering user is in another cell, at a distance r_m from its cell site (base station) and r_0 from the cell site of the desired user, the interference in the desired cell site i.e othercell interference is

$$\begin{aligned} I(r_0, r_m) &= P\left(\frac{10^{\xi_0/10}}{r_0^4}\right)\left(\frac{r_m^4}{10^{\xi_0/10}}\right) \\ &= P\left(\frac{r_m}{r_0}\right)^4 10^{(\xi_0-\xi_m)/10} \leq 1 \end{aligned} \qquad (2.2)$$

where the first term is due to the attenuation caused by distance and shadowing to the given cell, while the second term is the effect of power control to compensate attenuation to the cell site of the out-of-cell interferer. Of course ξ_0 and ξ_m are independent so that the difference has zero mean and variance $2\sigma^2$ Normalizing the hexagonal radius to unity, let K be the number of users in a cell so the density of users in per unit area is

$$\rho = \frac{2K}{3\sqrt{3}} \qquad (2.3)$$

The total othercell interference is given by

$$I = P\int\int_{Area}(\frac{r_m}{d_0})^4(10^{(\xi_{d,0}-\xi_{d,m})/10}) \times \phi(\xi_{d,0}-\xi_{d,m}, \frac{d_0}{r_m})\rho dA \quad (2.4)$$

where

$\phi(\xi_{d,0}-\xi_{d,m}, \frac{d_0}{r_m}) = 1$ if $(\frac{r_m}{d_0})^4(10^{(\xi_{d,0}-\xi_{d,m})/10}) \leq 1$

$= 0$ otherwise

where m is the cell-site index for which

$$r_m^4 10^{-\xi_m} = min\ r_n^4 10^{-\xi_n} \quad (2.5)$$

Hence mean value of interference is

$$E[I] = P\int\int_{Area}\alpha(\frac{r_m}{d_0})^4 f(\frac{r_m}{d_0})\rho dA \quad (2.6)$$

where

$$f(\frac{r_m}{d_0}) = exp[(\sigma ln10/10)^2]\{1 - Q[\frac{40}{\sqrt{2\sigma^2}}log_{10}(\frac{r_m}{d_0}) - \sqrt{2\sigma^2}\frac{ln10}{10}]\} \quad (2.7)$$

The integral is numerically evaluated for the $\sigma = 8$ db over the two-dimensional area

$$E[I] \leq (.658KP) \quad (2.8)$$

2.4.2 Circular sectorization

Let us divide the cell in two circular sectors having different density of users. Inner circular sector is of radius 'a'. Let us assume there are $K_0 + K_1$ users in cell. First consider only path loss without any shadowing loss Assuming the cells are circular with unit radius so outer cell sector extends from a to 1

Hence interference from inner sector is

$$I_{s0} = \sum_{j=1}^{\infty}\frac{K_0}{a^2\pi}\int_0^a\int_0^{2\pi}(\frac{r}{\sqrt{r^2+d^2-2rd\cos(\theta)}})^4 r\,dr d\theta \quad (2.9)$$

where K_0 is the number of mobile in inner sector, d is the distance of other cell base station to base station of reference cell, interfering mobile is located at (r, θ) assuming reference cell is at origin and interference from outer sector is,

$$I_{s1} = \sum_{j=1}^{\infty}\frac{K_1}{(1-a^2)\pi}\int_a^1\int_0^{2\pi}(\frac{r_1}{\sqrt{r_1^2+d^2-2r_1 d\cos(\theta)}})^4 r_1 dr_1 d\theta \quad (2.10)$$

where K_1 is the number of user in outer sector and interfering mobile is located at (r_1, θ_1). Hence total othercell interference is

$$I_{oci} = I_{s_0} + I_{s_1} \tag{2.11}$$

Consider soft hand off being only in the outer sectors of the cells. This is correct if we use tilted antenna for the inner cell

Then othercell interference is given by

$$I_{s_1} = \sum_{j=1}^{\infty} \frac{K_1}{(1-a^2)\pi} \int_a^1 \int_0^{2\pi} \left(\frac{r_1}{\sqrt{r_1^2+d^2-2r_1 d\cos(\theta)}}\right)^4 E[10^{(\xi_1-\xi_0)}, min(r_j 10^{\xi_j/10} \le r_0 10^{\xi_0/10})] r_1 dr_1 d\theta$$

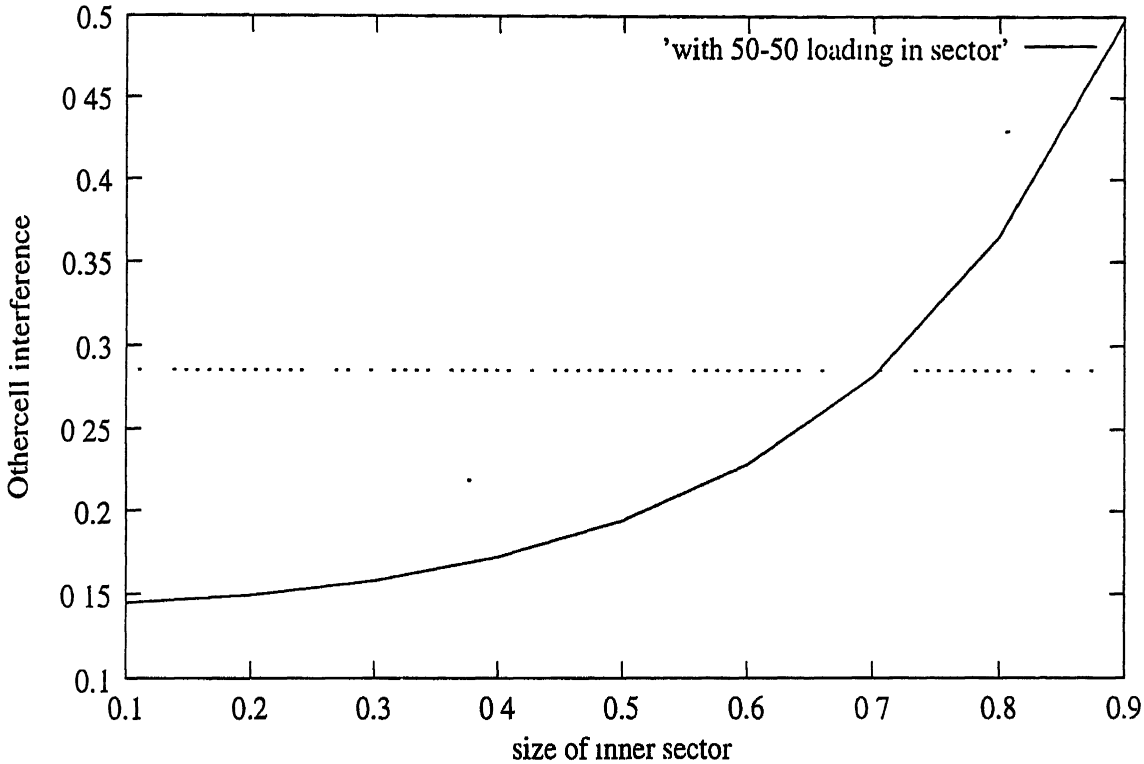

Figure 2.2: Variation of othercell interference with size of inner sector

Figure 2.2 shows the effect of sector size in circular sector case on the othercell interference. Figure shows that with the increase of the inner sector radius the total othercell interference from the first tier of the cell increases. This is because as inner sector radius increases density of users in the outer sector increases, which increases interference received at mobile of reference. Curve with dotted line is corresponding to case when density of users in whole cell is same.

2.4.3 Hot spots

Let us consider the case, in which there is a hot spot in a cell assuming the cells are circular with unit radius. By a hot spot we mean that the density of mobiles in a particular area is much higher compared to that in the rest of cell Let us assume there are $K_0 + K_1$ users in cell Let hot spot is circular and of radius 'a' and it is at k distance from base station Assume hot spot being too small as compared to cell. In this analysis only path loss is considered Then interference from hot spot is

$$I_{s_h} = \sum_{j=1}^{\infty} \frac{K_0}{a^2\pi} \int_0^a \int_0^{2\pi} \left(\frac{r_1}{\sqrt{r_1^2 + d_j^2 - 2r_1 d cos(\theta_1)}}\right)^{\gamma} r\, dr\, d\theta \tag{2.12}$$

where K_0 is the number of users in hot spot, interfering mobile is at (r, θ) in hot spot d_j is distance between the interfering base station and base station of reference, r_1 is its distance from base station, θ_1 is the angle it makes with reference base station and K_0 is the number of users in hot spot.

Now interference from rest of the cell is

$$I_{s_r} = \sum_{j=1}^{\infty} \frac{K_1}{(1-a^2)\pi} \int_0^1 \int_0^{2\pi} \left(\frac{r}{\sqrt{r^2 + d_j^2 - 2r\, d cos\theta}}\right)^{\gamma} r\, dr\, d\theta \tag{2.13}$$

where mobile of interference is at (r, θ) in its cell and K_1 is the number of users in rest of the cell

Hence total othercell interference is given by

$$I_{oc} = I_{s_h} + I_{s_r} \tag{2.14}$$

At particular position the interference from the hot spot becomes equal to that from rest of cell, whatever be the loading in hot spot Figure 2.3 shows the effect of change of the location of the hot spot in cell with different loading in hot spot on the othercell interference. All these curves for the different distribution of users in hot spot and rest of cell intersect when hot spot is at particular distance from the base station. The distance of hot spot from the centre (base station) is .67 when hot spot is of .1 unit diameter This is because of the reason that at this particular distance per user interference form the hot spot and that from rest of the cell is same. So this becomes independent of the percentage of users in hot spot. This intersection point is a function of size of hot spot as

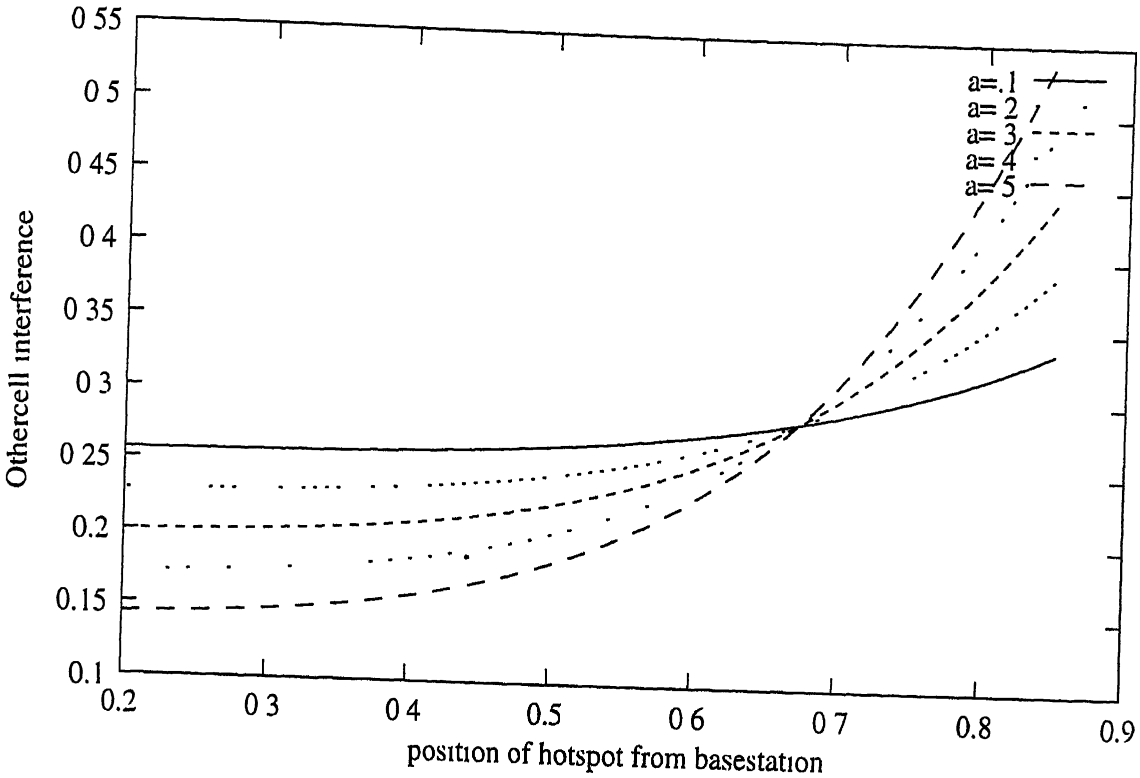

Figure 2.3 Variation of othercell interference with hot spot of size .05 radius in cell with the location of hot spot

we increase the size of hot spot (radius), effective per user interference decreases. Hence this intersection point is at large distance from the base station

Chapter 3

Resource Allocation

In this chapter, we consider the problem of allocating resources i.e PG and power for both uplink as well as downlink in the presence of othercell interference and imperfect power control. We first allocate the resources for the uplink and then the downlink.

3.1 Model

We assume there are two classes of asynchronous users - voice and data with fixed number of users in both the classes. Each class has its own traffic distribution and QoS requirement. We consider two type of cases.

- Random voice and continuously active data users.
- Random voice and random data users.

Random means each user generates a sequence of fixed length packets according to a Poisson process with rate λ. So a packet may experience queueing delay, transmission delay etc. This corresponds to transmission of short bursts. Continuously active means each user generates a new packet as soon as preceding packet is delivered successfully. Packets experience only transmission delay and no queueing delay. This corresponds to a situation in which all users are transmitting long files.

Let λ be the rate at which a source is generating packets and S be the average time taken to successfully transmit a packet including retransmission time. Then, p_{on} - the

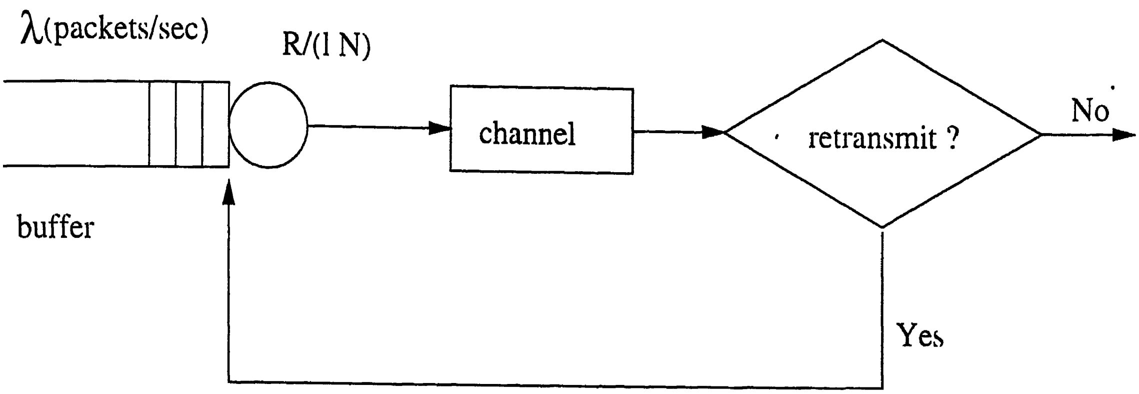

Figure 3 1. Data traffic model

probability that a user is active at any instant is given by Little's formula [14].

$$\begin{aligned} p_{on} &= \lambda S \quad if \;\; \lambda S < 1 \\ &= 1 \qquad otherwise \end{aligned} \tag{3 1}$$

$\lambda S > 1$ implies average packet waiting time (queueing time) is infinite.
Voice packet transmission time $T = \frac{lN}{R}$ where l is length of packet N is PG and R is chip rate The stability condition $\lambda S < 1$ implies that PG

$$N \leq N_{max} = \frac{R}{\lambda l} \tag{3 2}$$

For continuously active case, data users retransmit packets which are received erroneously. We wait for Negative AcKnowledgement (NAK) for some finite time after transmission. If NAK is received within that time, we send the packet again instantly We assume that NAK receiving time t is uniformly distributed in [0,U].
If δ denotes the transmission time of a packet then

$$Pr[\delta = T + j(t+T)] = p_r^j(1-p_r)$$

where j is the number of retransmission request and p_r is probability of retransmission

The average packet transmission time is given by

$$\begin{aligned} D &= E[\delta] \\ &= \frac{(U/2+T)p_r}{(1-p_r)} + T \end{aligned} \tag{3 3}$$

But in the case of random data user, packet is retransmitted after completion of transmission of the current packet i.e. residual time of outgoing packet Queueing time

is also included in this case Residual time r, of outgoing packet is uniformly distributed in [0,T]

Let B be packet transmission time then

$$Pr[B = T + j(t + r + T)] = p_r^j(1 - p_r)$$

$$E[B] = \frac{(U/2 + T/2 + T)p_r}{(1 - p_r)} + T \tag{3.4}$$

Let Δ denote the time, packet occupies the channel for successful transmission Then Δ has the geometrical distribution

$$Pr[\Delta = jT] = p_r^{j-1}(1 - p_r)$$

where $j = 1,2$ is the number of transmission necessary for successful reception.

Considering M/G/1 queueing model with infinite length buffer. then average waiting time in queue W is given by

$$W = \frac{\lambda E[\Delta^2]}{2(1 - p_{on})} = \frac{\lambda T^2(1 + p_r)}{2(1 - p_{on})(1 - p_r)^2} \tag{3.5}$$

where

$$p_{on} = \frac{\lambda l N}{R(1 - p_r)}$$

Therefore total average packet delay for the user is

$$D = E[B] + W \tag{3.6}$$

To satisfy the BER requirement for the data traffic, the probability of an undetected error must be no greater that the target BER. Since we assume that all errors are detected the BER requirement for data traffic is automatically satisfied in the model We focus on satisfying a delay constraint (i e on average delay) In contrast, for voice traffic we assume that the maximum delay, D = LN_{max}/R, is acceptable and focus on satisfying a constraint on the average BER p_b .

3.2 Uplink

In uplink interference is not only from the users in other cells but also from the users in its cell We assume that users of all the classes are uniformly distributed in all the cells. The packet length and coding have also been taken to be same for both the classes

3.2.1 Random Voice and Continuously Active Data Users

Let the number of voice users be K_v and the number of data users be K_d. As voice users are randomly active, we consider a voice user to be ON with probability p_{on_v} and OFF with probability $(1 - p_{on_v})$. The number of active voice users at a time is random. Data users are continuously active i.e. their probability of ON is 1.

Let P_v, N_v be the power and PG of voice users and P_d, N_d be that of data users. The resource allocation problem is the assignment of power and PG i.e. P_v, P_d, N_v, N_d so that QoS and rate requirements are satisfied. Specifically, we wish to maximize the throughput of the data users denoted as η_d for fixed number of voice and data users subject to a QoS constraint for the voice users. For voice user p_{on_v} is a function of N_v.

$$p_{on_v} = \lambda_v l_v N_v / R \tag{3.7}$$

where R is chip rate. We have maximized η_d for a given value of N_v.

$$\max_{P_v, P_d, N_d} \eta_d \text{ subject to the constraints}$$

$$p_{b_v} \leq \epsilon_v, \; P_v \leq \mathcal{P}_v, \; and \; P_d \leq \mathcal{P}_d \tag{3.8}$$

where ϵ_v is maximum acceptable BER of voice users while $\mathcal{P}_v$ and $\mathcal{P}_d$ are the maximum allowed power level of voice and data users respectively.

The received signal corresponding to a voice user after match filter detection can be expressed as

$$r = \alpha_1 A_v b_1 + \sum_{i=2}^{K_v - 1} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d} \alpha_j A_d b_j \rho_{1j} + I_v + I_d + \eta \tag{3.9}$$

where

A_v = signal amplitude of voice user,

A_d = signal amplitude of data user,

I_v = othercell interference corresponding to voice users in othercells,

I_d = othercell interference corresponding to data users in othercells,

ϕ_v = random variable which is 1 with probability p_{on_v} and 0 with probability (1 - p_{on_v}). It is assumed to be i.i.d for each transmitted symbol,

η = thermal noise $\mathcal{N}(0, \sigma^2)$,

b_i = bit transmitted $b_i \in [1, -1]$ with equal probability,

ρ_{1j} = correlation of signature sequence of j^{th} mobile to mobile of reference.

α_i = lognormally distributed random variable to model the imperfection in power control. It is assumed to be i.i.d. for all users. When α =1 it corresponds to perfect power control

r can be expressed as a summation of two terms as

$$r = X_v + \eta \tag{3.10}$$

where

$$X_v = \alpha_1 A_v b_1 + \sum_{i=2}^{K_v - 1} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d} \alpha_j A_d b_j \rho_{1j} + I_v + I_d \tag{3.11}$$

so probability of bit error of voice user [11] is given by

$$p_{b_v} = E\left[Q(\frac{X_v}{\sigma})\right] \tag{3.12}$$

The expectation in above expression is over the interference and power control statistics. Conditioning on the statistics, an expression for the above probability of error can be evaluated but its complexity increases exponentially as the number of users in the system. Hence using the first and second moments of the interference and power control statistics, an approximation for p_{b_v} can be given by

$$p_{b_v} \approx \frac{2}{3}Q\left[\frac{E(X_v)}{\sigma}\right] + \frac{1}{6}Q\left[\frac{E(X_v) + \sqrt{(3)}\sigma_{X_v}}{\sigma}\right] + \frac{1}{6}Q\left[\frac{E(X_v) - \sqrt{(3)}\sigma_{X_v}}{\sigma}\right] \tag{3.13}$$

The details of derivation of the above equation are given in Appendix A. It is seen that the approximation given in above equation is fairly accurate over wide range of interferer power levels.

3.2.1.1 Othercell interference

Following the method of [7], othercell Interference from voice users is given by

$$I_v = A_v b_i \iint_{Area} \alpha k \phi_v (\frac{r_m}{d_0})^2 (10^{(\xi_{d,0} - \xi_{d,m})/10}) \times \psi(\xi_{d,0} - \xi_{d,m}, \frac{d_0}{r_m}) \rho_v dA \tag{3.14}$$

where,

$\psi(\xi_{d,0} - \xi_{d,m}, \frac{d_0}{r_m}) = 1$ if $(\frac{r_m}{d_0})^4 (10^{(\xi_{d,0} - \xi_{d,m})/10}) \leq 1$

$= 0$ otherwise

and ξ is Gaussian distributed with zero mean and standard deviation $\sigma_1 = 8$db. ρ_v is the density of mobiles and k - the correlation coefficient of signature sequence of that mobile to the mobile of reference and is taken to be $1/\sqrt{N_v}$

Simileraly othercell interference from data users is given by

$$I_d = A_d b_i \int\int_{area} \alpha k \phi_d (\frac{r_m}{d_0})^2 (10^{(\xi_{d,0}-\xi_{d,m})/10}) \times \psi(\xi_{d,0} - \xi_{d,m}, \frac{d_0}{r_m}) \rho_d dA \qquad (3.15)$$

Since $E[b_i] = 0$, therefore the expected value and variance of I_v and I_d can be given as

$$\begin{aligned} E[I_v] &= E[I_d] = 0 \\ Var\,[I_v] &\le (.658 p_{on_v} K_v P_v m)/N_v \\ Var\,[I_d] &\le (.658 p_{on_d} K_d P_d m)/N_d \end{aligned} \qquad (3.16)$$

where $P_v = A_v^2$, $P_d = A_d^2$, $E[\alpha] = \mu$ and $E[\alpha^2]$=m

Since $E[b_i] = 0$, so mean of $\sum_{i=2}^{K_v-1} \alpha_i \phi_v A_v b_i \rho_{1i} = 0$ and variance of this term is

$$\begin{aligned} &= E\left[(\sum_{i=2}^{K_v-1} \alpha_i \phi_v A_v b_i \rho_{1i})^2\right] \\ &= E\left[\sum_{i=2}^{K_v-1} \alpha_i^2 \phi_v^2 A_v^2 \rho_{1i}^2 + \sum_{i,k} A_v^2 b_i b_k \rho_{1i} \rho_{1k}\right] \\ &= E\left[\sum_{i=2}^{K_v-1} \alpha_i^2 \phi_v^2 A_v^2 \rho_{1i}^2\right] \\ &= (K_v - 1) A_v^2 p_{on_v} m/N_v, \end{aligned} \qquad (3.17)$$

by using the results [12]

$$E_1[\rho_{1k}\rho_{1l}] = \frac{\rho_{kl}}{N_v} \qquad (3.18)$$

Similarly mean and variance of second term can be calculated

Refer to Eqn. 3.11,

$$E[X_v] = \mu A_v = \mu\sqrt{P_v} \qquad (3.19)$$

Variance of X_v, $\sigma_{X_v}^2$ is

$$Var\,[X_v] = [(K_v - 1)A_v^2 p_{on_v} m + K_d A_d^2 m + .658 p_{on_v} A_v^2 K_v m + .658 K_d A_d^2 m$$

$$
\begin{aligned}
&+(m-\mu^2)A_v^2]/N_v \\
&= [(K_v-1)P_v p_{on_v} m + K_d P_d m + .658 p_{on_v} P_v K_v m + .658 K_d P_d m \\
&+(m-\mu^2)P_v]/N_v \qquad (3.20)
\end{aligned}
$$

Since throughput of a data user cannot be maximized with respect to both P_v and P_d so fix P_v or P_d and determine optimal value of other such that voice users satisfy BER equivalently. Thus the data throughput is maximized for a given value of P_v, P_d and X_v.

The received signal corresponding to a data user after match filter detection can be expressed as

$$
r = \alpha_1 A_d b_1 + \sum_{i=2}^{K_v} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d-1} \alpha_j A_d b_j \rho_{1j} + I_v + I_d + \eta \qquad (3.21)
$$

r can be expressed as a summation of two terms as

$$
r = X_d + \eta \qquad (3.22)
$$

where,

$$
X_d = \alpha_1 A_d b_1 + \sum_{i=2}^{K_v} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d-1} \alpha_j A_d b_j \rho_{1j} + I_v + I_d \qquad (3.23)
$$

So probability of bit error of data user is

$$
p_{b_d} = \frac{2}{3} Q\left[\frac{E(X_d)}{\sigma}\right] + \frac{1}{6} Q\left[\frac{E(X_d) + \sqrt{(3)}\sigma_{X_d}}{\sigma}\right] + \frac{1}{6} Q\left[\frac{E(X_d) - \sqrt{(3)}\sigma_{X_d}}{\sigma}\right] \qquad (3.24)
$$

Refer to Eqn. 3.23.

$$
E[X_d] = \mu A_d = \mu\sqrt{P_d} \qquad (3.25)
$$

Variance of X_d, $\sigma^2_{X_d}$ is

$$
\begin{aligned}
Var[X_d] &= [K_v A_v^2 p_{on_v} m + (K_d-1)A_d^2 m + .658 p_{on_v} A_v^2 K_v m + .658 K_d A_d^2 m \\
&+(m-\mu^2)A_d^2]/N_d \\
&= [K_v P_v p_{on_v} m + (K_d-1)P_d m + .658 p_{on_v} P_v K_v m + .658 K_d P_d m \\
&+(m-\mu^2)P_d]/N_d \qquad (3.26)
\end{aligned}
$$

Retransmission probability of data packet is

$$p_{rd} = 1 - (1 - p_{b_d})^{lk} \tag{3.27}$$

where k is code rate. Hence average packet delay is

$$D = \frac{2.5lN_d p_{rd}}{R(1 - p_{rd})} + \frac{lN_d}{R} \tag{3.28}$$

Thus the average throughput - average rate of successful transmission of symbol, is

$$\eta_d = \frac{kl}{D} \tag{3.29}$$

Differentiating the throughput w.r.t. N_d and equating it to zero gives the value of N_d at which data throughput is maximum for a given value of N_v

3.2.2 Random Voice and Random Data users

Both voice and data users are random in this case. In this case N_d effects the performance of both voice and data users. An increase in N_d causes decrease in P_d, but this increases p_{on_d} that in turn increases the interference for the data users.

This case is different from the previous case in that P_v and P_d cannot be directly determined as the value of p_{on_d} is not known and hence p_{rd} is not known as it depends on p_{on_d} or vice versa. For each value of N_d solution does not exist because delay may become infinite.

The received signal corresponding to voice user after match filter detection is expressed as

$$r = \alpha_1 A_v b_1 + \sum_{i=2}^{K_v-1} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d} \alpha_j \phi_d A_d b_j \rho_{1j} + I_v + I_d + \eta \tag{3.30}$$

r can be expressed as a summation of two terms as

$$r = X_v + \eta \tag{3.31}$$

where,

$$X_v = \alpha_1 A_v b_1 + \sum_{i=2}^{K_v-1} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d} \alpha_j \phi_d A_d b_j \rho_{1j} + I_v + I_d \tag{3.32}$$

So probability of bit error of voice user is

$$p_{b_v} = \frac{2}{3}Q\left[\frac{E(X_v)}{\sigma}\right] + \frac{1}{6}Q\left[\frac{E(X_v)+\sqrt{(3)}\sigma_{X_v}}{\sigma}\right] + \frac{1}{6}Q\left[\frac{E(X_v)-\sqrt{(3)}\sigma_{X_v}}{\sigma}\right] \tag{3.33}$$

Refer to Eqn. 3.32,

$$E[X_v] = \mu A_v = \mu\sqrt{P_v} \tag{3.34}$$

Variance of X_v, $\sigma^2_{X_v}$ is

$$\begin{aligned} Var[X_v] &= [(K_v-1)A_v^2 p_{on_v} m + K_d A_d^2 p_{on_d} m + .658 p_{on_v} A_v^2 K_v m + .658 p_{on_d} K_d A_d^2 m \\ &\quad + (m-\mu^2)A_v^2]/N_v \\ &= [(K_v-1)P_v p_{on_v} m + K_d P_d p_{on_d} m + .658 p_{on_v} P_v K_v m + .658 p_{on_d} K_d P_d m \\ &\quad + (m-\mu^2)P_v]/N_v \end{aligned} \tag{3.35}$$

The received signal corresponding to data user after match filter detection can be expressed as

$$r = \alpha_1 A_d b_1 + \sum_{i=2}^{K_v} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d-1} \alpha_j \phi_d A_d b_j \rho_{1j} + I_v + I_d + \eta \tag{3.36}$$

r can be expressed as a summation of two terms as

$$r = X_v + \eta \tag{3.37}$$

where,

$$X_d = \alpha_1 A_d b_1 + \sum_{i=2}^{K_v} \alpha_i \phi_v A_v b_i \rho_{1i} + \sum_{j=1}^{K_d-1} \alpha_j \phi_d A_d b_j \rho_{1j} + I_v + I_d \tag{3.38}$$

So probability of bit error of data user is

$$p_{b_d} = \frac{2}{3}Q\left[\frac{E(X_d)}{\sigma}\right] + \frac{1}{6}Q\left[\frac{E(X_d)+\sqrt{(3)}\sigma_{X_d}}{\sigma}\right] + \frac{1}{6}Q\left[\frac{E(X_d)-\sqrt{(3)}\sigma_{X_d}}{\sigma}\right] \tag{3.39}$$

Refer to Eqn. 3.38,

$$E[X_d] = \mu A_d = \mu\sqrt{P_d} \tag{3.40}$$

Variance of X_d, $\sigma^2_{X_d}$ is

$$\begin{aligned} Var[X_d] &= [K_v A_v^2 p_{on_v} m + (K_d - 1) A_d^2 p_{on_d} m + 658 p_{on_v} A_v^2 K_v m + 658 p_{on_d} K_d A_d^2 m \\ &\quad + (m - \mu^2) A_d^2]/N_d \\ &= [K_v P_v p_{on_v} m + (K_d - 1) P_d p_{on_d} m + 658 p_{on_v} P_v K_v m + 658 p_{on_d} K_d P_d m \\ &\quad + (m - \mu^2) P_d]/N_d \end{aligned} \quad (3.41)$$

Retransmission probability of the data users is given by

$$p_{r_d} = 1 - (1 - p_{b_d})^{lk} \quad (3.42)$$

Probability of ON of data is

$$\begin{aligned} p_{on_d} &= \frac{\lambda_d l_d N_d}{R(1 - p_{r_d})} \quad if \quad \frac{\lambda_d l_d N_d}{R(1 - p_{r_d})} < 1 \\ &= 1 \qquad otherwise \end{aligned} \quad (3.43)$$

Algorithm for computing the minimum delay of data packet is as below.
For a given value of N_v

1. Compute the initial value of p_{on_d} such that $0 \le p_{on_d} \le 1$.
2. For fixed $P_v = \mathcal{P}_v (P_d = \mathcal{P}_d)$ compute $P_d(P_v)$ to achieve $p_{b_v} = \epsilon_v$ from Eqn. (3.33).
3. Compute p_{r_d} from Eqn. (3.42)
4. Compute the new value of p_{on_d} from Eqn. (3.43)
5. Iterate steps 2 - 4 until convergence. When the difference becomes less than 10^{-7} we have assumed convergence
6. Compute D corresponding to converged values from Eqn (2.6)
7. Minimize D w.r.t. N_d

3.3 Downlink

Downlink is different from the uplink in that, there is no same cell interference. This is because all the channels are orthogonal to each other. In this case interfering sources

are the other cell base stations It is assumed that received power by the mobiles of a particular class is same It is also assumed that users of both classes are uniformly distributed in cells Assuming the cells are circular with unit radius

3.3.1 Random voice and continuously active data users

Received signal at the mobile of reference which is at location (r_1, θ) in its cell is given by

$$r = A_v + \sum_{k=1}^{\infty}\sum_{j=1}^{K_v} \phi_j A_v b_j g_{rj} + \sum_{k=1}^{\infty}\sum_{i=1}^{K_d} A_d b_i g_{ri} + \eta \quad (3.44)$$

where A_v and A_d are the received signal of voice and data users respectively and g_{rj} is

$$g_{rj} = \frac{r_j^2}{D_k^2} \quad (3.45)$$

where r_j is the distance of j^{th} mobile from its base station D is the distance of its base station from the reference mobile Let r_j be uniformly distributed between (0,R) i e $r_j \in U[0, R]$ and θ be also uniformly distributed i e. $\theta \in U[0, 2\pi]$

Applying central limit theorem to Eqn 3.44, the PDF of r can be approximated as Gaussian. Hence, the probability of bit error for voice user can be given as

$$p_{b_v} = \frac{1}{2} erfc(\frac{E[r]}{\sqrt{Var[r]}}) \quad (3.46)$$

Average value of signal received by voice user is

$$E[r] = A_v = \sqrt{P_v} \quad (3.47)$$

$$\begin{aligned} E\left[r^2|r_1, \theta\right] &= \sum_{k=1}^{\infty} K_v p_{on_v} A_v^2 E\left[r_j^4\right] \frac{1}{D_k^4} + \sum_{k=1}^{\infty} K_d A_d^2 E\left[r_i^4\right] \frac{1}{D_k^4} + \sigma^2 \\ &= \sum_{k=1}^{\infty} K_v p_{on_v} A_v^2 \frac{1}{D_k^4}/5 + \sum_{k=1}^{\infty} K_d A_d^2 \frac{1}{D_k^4}/5 + \sigma^2 \end{aligned} \quad (3.48)$$

$$Var[r] = E\left[r^2\right] = \int_{r=0}^{d/2}\int_{\theta=0}^{2\pi} E\left[r^2|r_1, \theta\right] f_{r_1}(r_1) f_\theta(\theta) dr_1 d\theta \quad (3.49)$$

Received signal corresponding to data user is

$$r = A_d + \sum_{k=1}^{\infty}\sum_{j=1}^{K_v} \phi_j A_v b_j g_{rj} + \sum_{k=1}^{\infty}\sum_{i=1}^{K_d} A_d b_i g_{ri} + \eta \quad (3.50)$$

Probability of bit error for the data user is

$$p_{b_d} = \frac{1}{2} erfc(\frac{E[r]}{\sqrt{Var[r]}}) \tag{3.51}$$

$E[r] = A_d = \sqrt{P_d}$

Variance is same as that of voice user.

Retransmission probability of packet = 1 - Probability of correct reception of packet

Hence retransmission probability is :

$$p_{rd} = 1 - (1 - p_{b_d})^{lk} \tag{3.52}$$

Thus, the average packet delay is

$$D = \frac{2.5lN_d p_{rd}}{R(1 - p_{rd})} + \frac{lN_d}{R} \tag{3.53}$$

So the average throughput is

$$\eta_d = \frac{kl}{D} \tag{3.54}$$

Differentiating the throughput w.r.t N_d and equating to zero gives the value of N_d at which data throughput is maximum for the given value of N_v.

3.3.2 Random voice and Random data users

Received signal at the mobile of reference which is at location (r_1, θ) in its cell is given by

$$r = A_v + \sum_{k=1}^{\infty} \sum_{j=1}^{K_v} \phi_j A_v b_j g_{rj} + \sum_{k=1}^{\infty} \sum_{i=1}^{K_d} \phi_i A_d b_i g_{ri} + \eta \tag{3.55}$$

where A_v and A_d are the received signal of voice and data users respectively and g_{rj} is

$$g_{rj} = \frac{r_j^2}{D_k^2} \tag{3.56}$$

where r_j is the distance of j^{th} mobile from its base station D is the distance of its base station from the reference mobile. Let r_j be uniformly distributed between (0,R) i.e. $r_j \in U[0, R]$ and θ be also uniformly distributed i.e. $\theta \in U[0, 2\pi]$.

Probability of bit error for voice user is

$$p_{b_v} = \frac{1}{2} erfc(\frac{E[r]}{\sqrt{Var[r]}}) \tag{3.57}$$

Average value of signal received by voice user is

$$E[r] = A_v = \sqrt{P_v} \tag{3.58}$$

$$\begin{aligned} E\left[r^2 | r_1, \theta\right] &= \sum_{k=1}^{\infty} K_v p_{on_v} A_v^2 E\left[r_j^4\right] \frac{1}{D_k^4} + \sum_{k=1}^{\infty} K_d p_{on_d} A_d^2 E\left[r_j^4\right] \frac{1}{D_k^4} + \sigma^2 \\ &= \sum_{k=1}^{\infty} K_v p_{on_v} A_v^2 \frac{1}{D_k^4} / 5 + \sum_{k=1}^{\infty} K_d p_{on_d} A_d^2 \frac{1}{D_k^4} / 5 + \sigma^2 \end{aligned} \tag{3.59}$$

$$Var[r] = E\left[r^2\right] = \int_{r_1=0}^{d/2} \int_{\theta=0}^{2\pi} E\left[r^2 | r_1, \theta\right] f_{r_1}(r_1) f_\theta(\theta) dr_1 d\theta \tag{3.60}$$

Received signal corresponding to data user is

$$r = A_d + \sum_{k=1}^{\infty} \sum_{j=1}^{K_v} \phi_j A_v b_j g_{ij} + \sum_{k=1}^{\infty} \sum_{i=1}^{K_d} \phi_i A_d b_i g_{ii} + \eta \tag{3.61}$$

Probability of bit error for the data user is

$$p_{b_d} = \frac{1}{2} erfc\left(\frac{E[r]}{\sqrt{Var[r]}}\right) \tag{3.62}$$

$E[r] = A_d = \sqrt{P_d}$

Variance is same as that of voice user.

The algorithm used for random voice and random data user for the uplink is also used in this case to calculate the minimum delay for the packet transmission of the data user

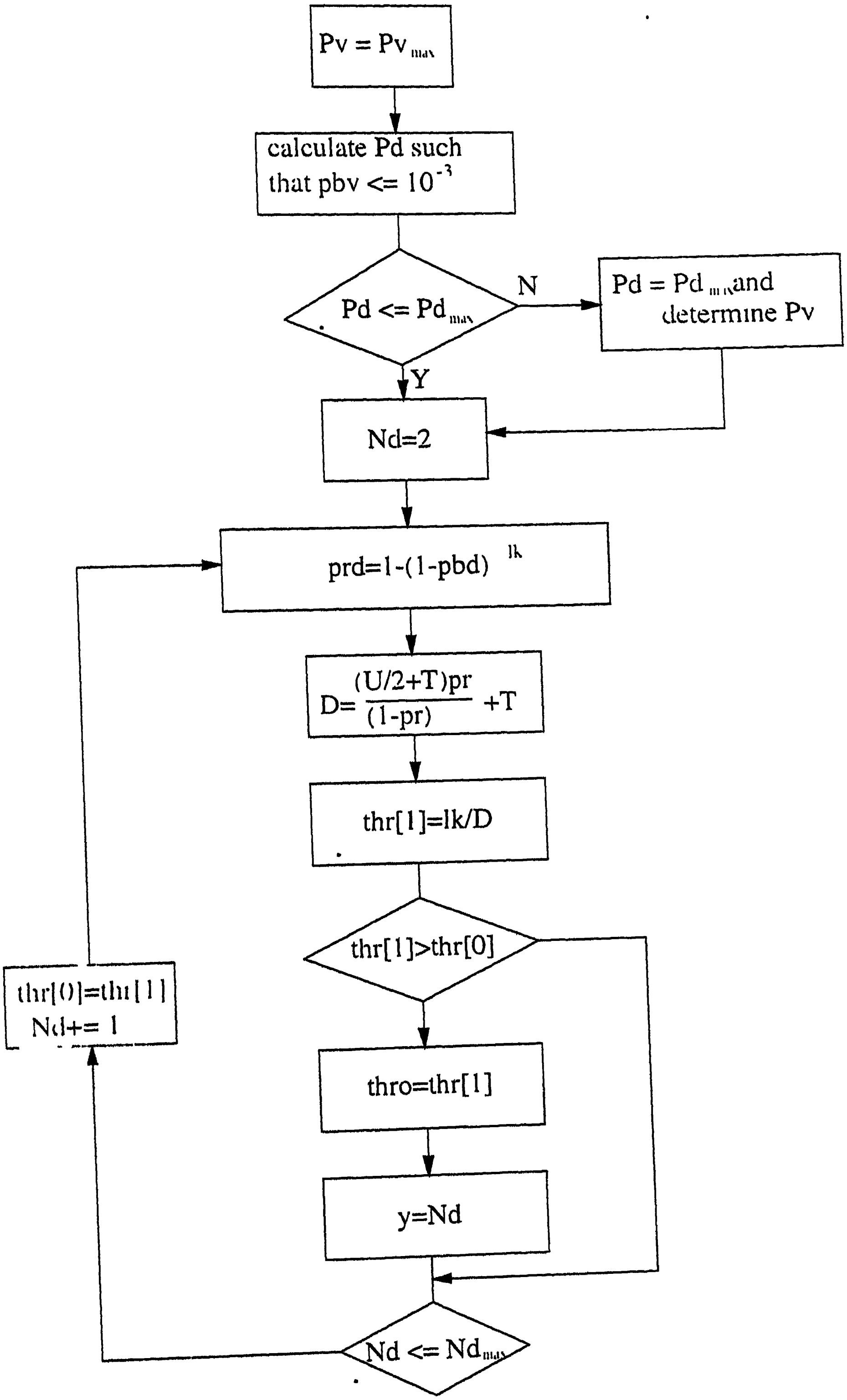

Figure 3.2: Flow chart for maximization of data throughput for random voice and continuous data users

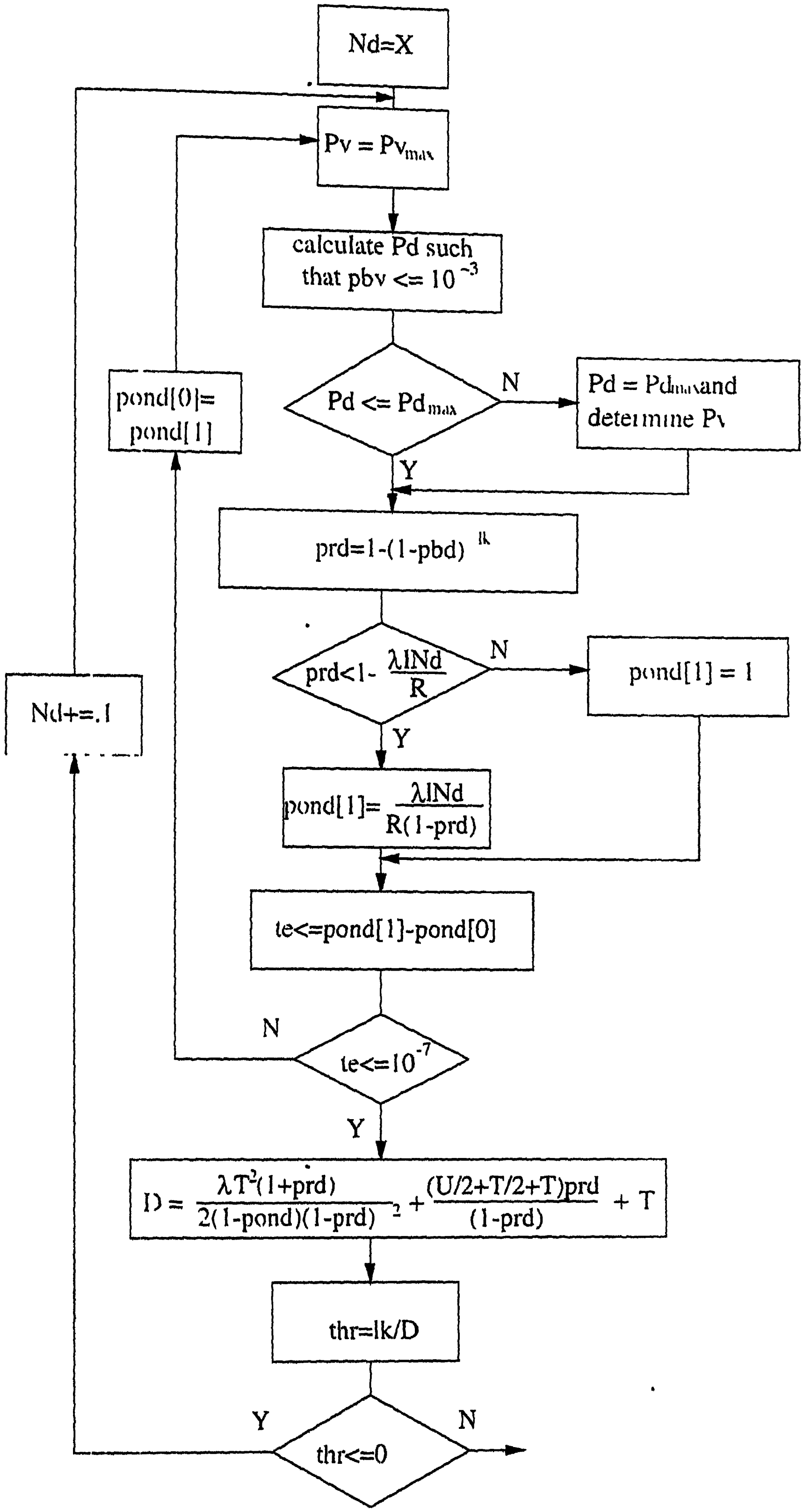

Figure 3.3: Flow chart for minimization of average packet delay random voice and random data users

Chapter 4

RESULTS

4.1 Result

In this chapter the results for both uplink and downlink are presented. Results are for the both models, i.e. random voice and continuously active data users and random voice and random data users. The values taken for different parameters are coding rate k = 1/2, packet length = 768 symbols, and chip rate is 5 Mchips/s. Packet arrival rate of the voice user = 18.75 packets/s (corresponding to 14.4 kb/s) and $U = 3T$. Imperfection in power control is 1.5db and standard deviation of shadowing σ_1 is 8db. Thermal noise standard deviation σ is 16dbm and maximum power of both voice and data user is 0.2 Watts.

4.2 Uplink

The algorithm is applied for 4 cases.

case 1- only same cell interference,

case 2 - both imperfect power control and same cell interference

case 3 - same cell as well as othercell interference

case 4 - same cell and othercell interference and imperfect power control

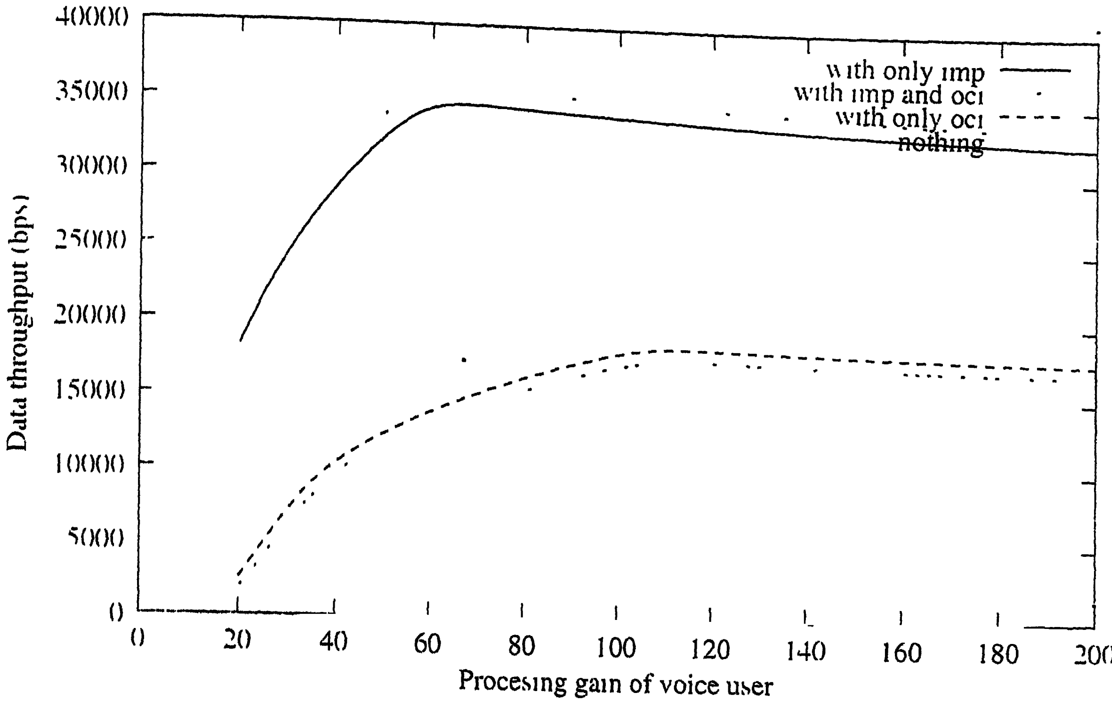

Figure 4.1 Data throughput for random voice and continuous data for Kd=10 and Kv=10 with λ_v=18.75 packets/s in uplink

In all Figures 'nothing' implies same cell interference case, 'with only imp' - both imperfect power control and same cell interference case, 'with only oci' - same cell as well as othercell interference case, 'with imp and oci' - same cell and othercell interference and imperfect power control case

4.2.1 Random Voice and Continuously Active Data Users

For the random voice and continuously active data users case Figure 4.1 corresponds to maximum data throughput, Figure 4.2 for optimal data power and Figure 4.3 for optimal voice power. As shown in Figure 4.1 data throughput first increases sharply (first phase) and then decreases very slowly with voice PG (second phase). Since in the first phase voice power is constant (maximum value), as voice PG increases data power also increases, so the optimal data throughput increases. But in the second phase data power is constant (maximum) and average voice power (p_{on}, P_v) increases slowly with voice PG. Othercell interference and imperfect power control affects the data throughput. As in Fig 1 for voice PG of 100 the maximum data throughput is 35121bps, 34049bps,

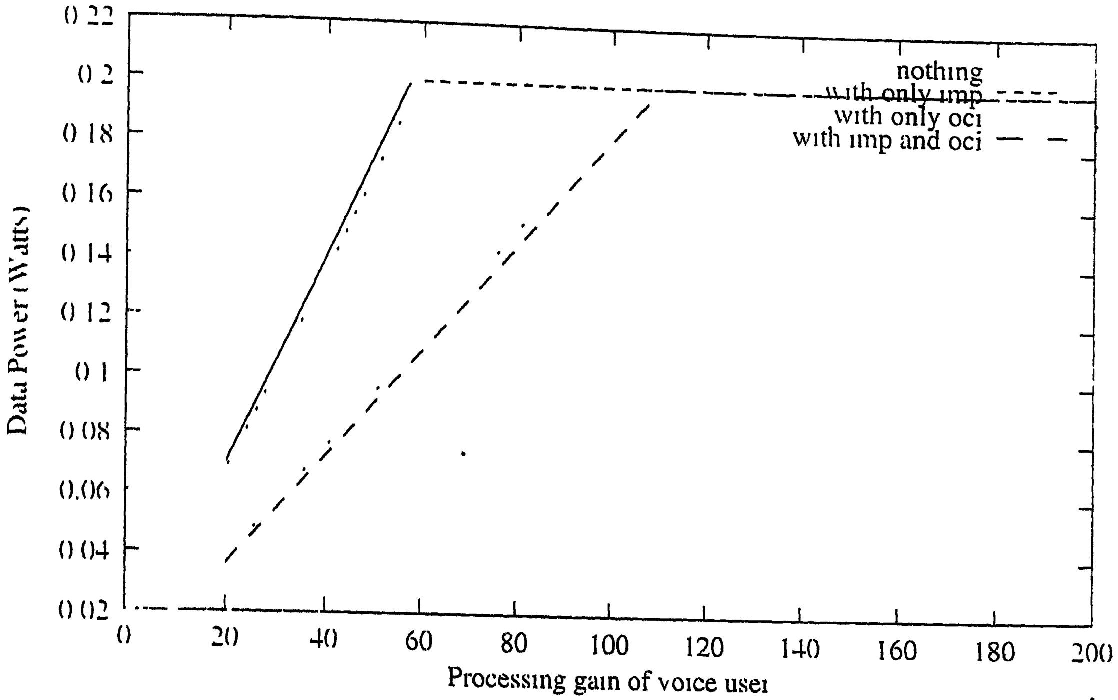

Figure 4.2. Data power for random voice and continuous data for Kd=10 and Kv=10 with λ_v 18.75 packets/s in uplink

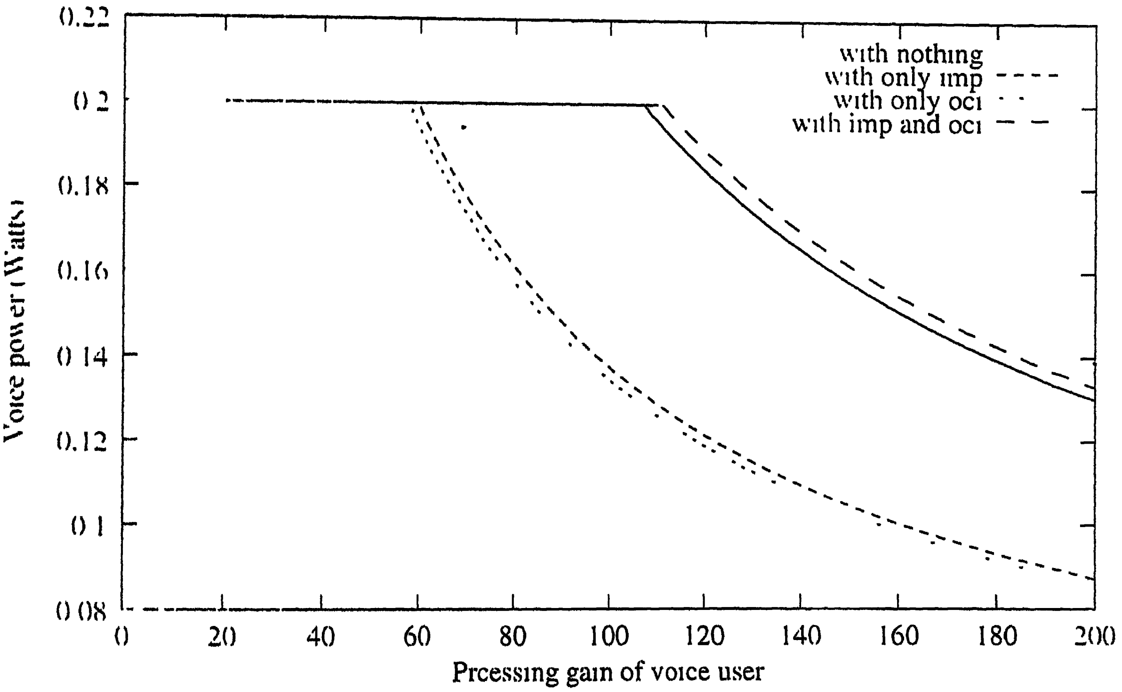

Figure 4.3: Voice power for random voice and continuous data for Kd=10 and Kv=10 with λ_v= 18 75 packets/s in uplink

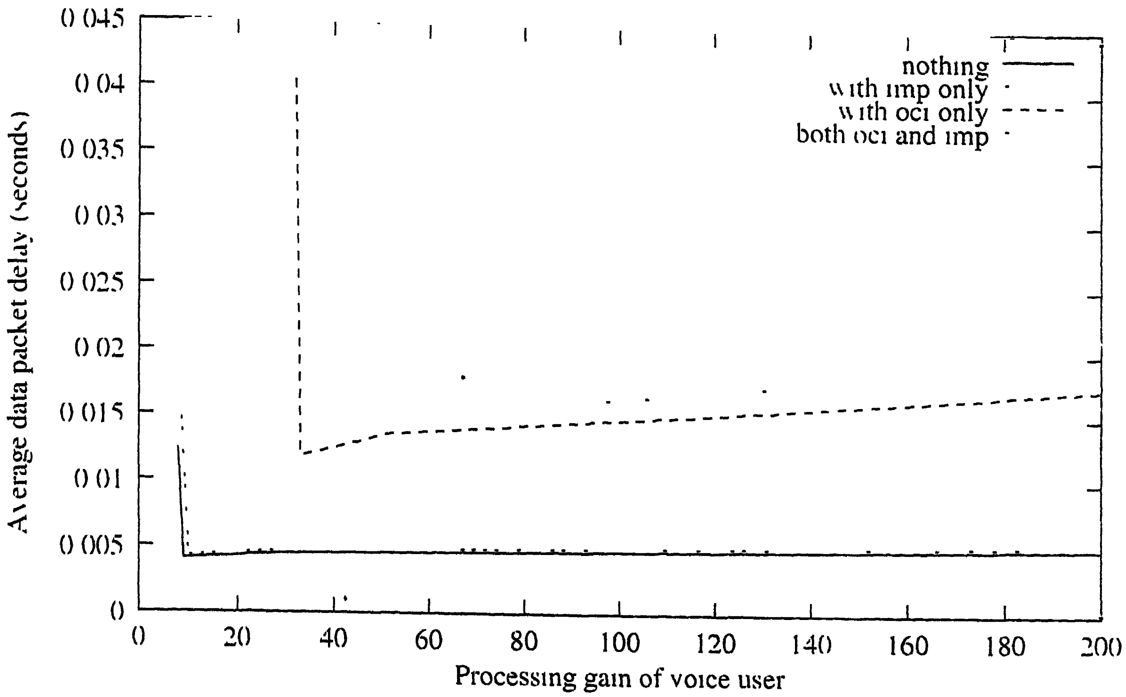

Figure 4.4. Average data packet delay for random voice and random data for Kd=6 and Kv=6 with λ_d=80 packets/s and λ_v=18.75 packets/s in uplink

18093bps and 17185bps for only same cell interference, both imperfect power control and same cell interference, same cell as well as othercell interference, and same cell and othercell interference with imperfect power control cases respectively

4.2.2 Random Voice and Random Data Users

In the case of random voice and random data users, due to very low value of the PG delay could be infinite for a given value of λ_d within the constraints This is because at low value of PG, $p_{i,d}$ makes $p_{on,d}$ equal to 1 which makes the average queuing delay infinite This is why the curves in Figures 4 4, 4 5 and 4 6 begin from different points on the x-axis. Figure 4.4 shows there is no data throughput below PG = 8 for only same cell interference The value of PG below which this occurs for both imperfect power control and same cell interference is about 8. For same cell as well as othercell interference it is about 32. While for same cell and othercell interference with imperfect power control case it is about 36

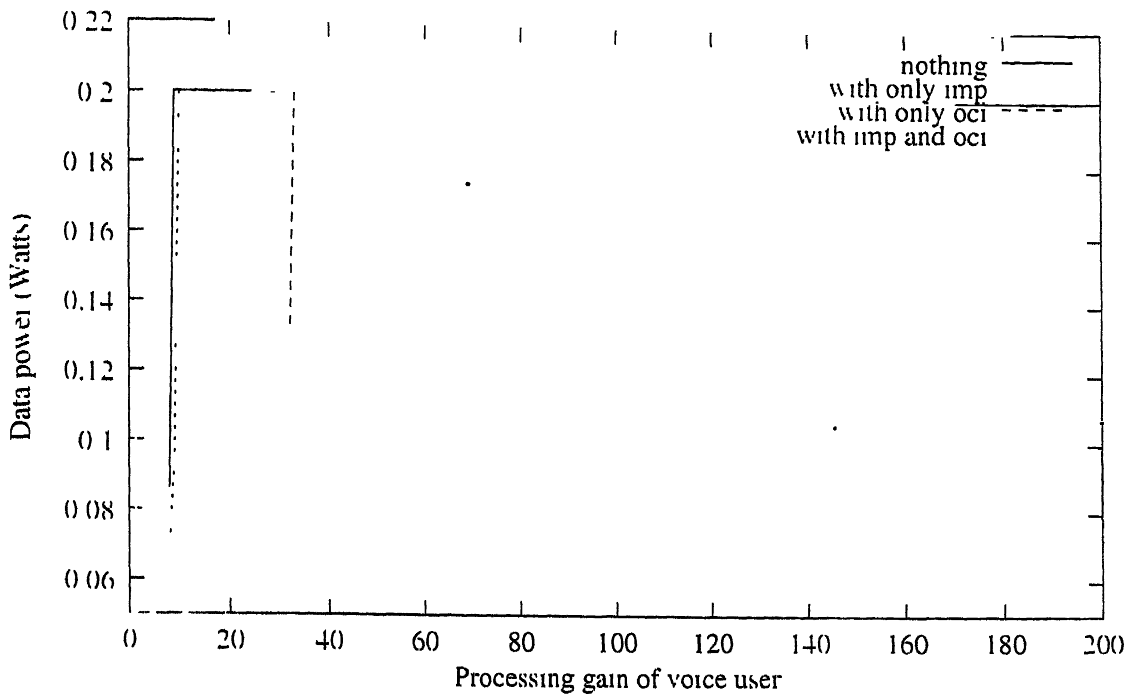

Figure 4.5: Data power for random voice and random data for Kd=6 and Kv=6 with λ_d=80 packets/s and λ_v=18.75 packets/s in uplink

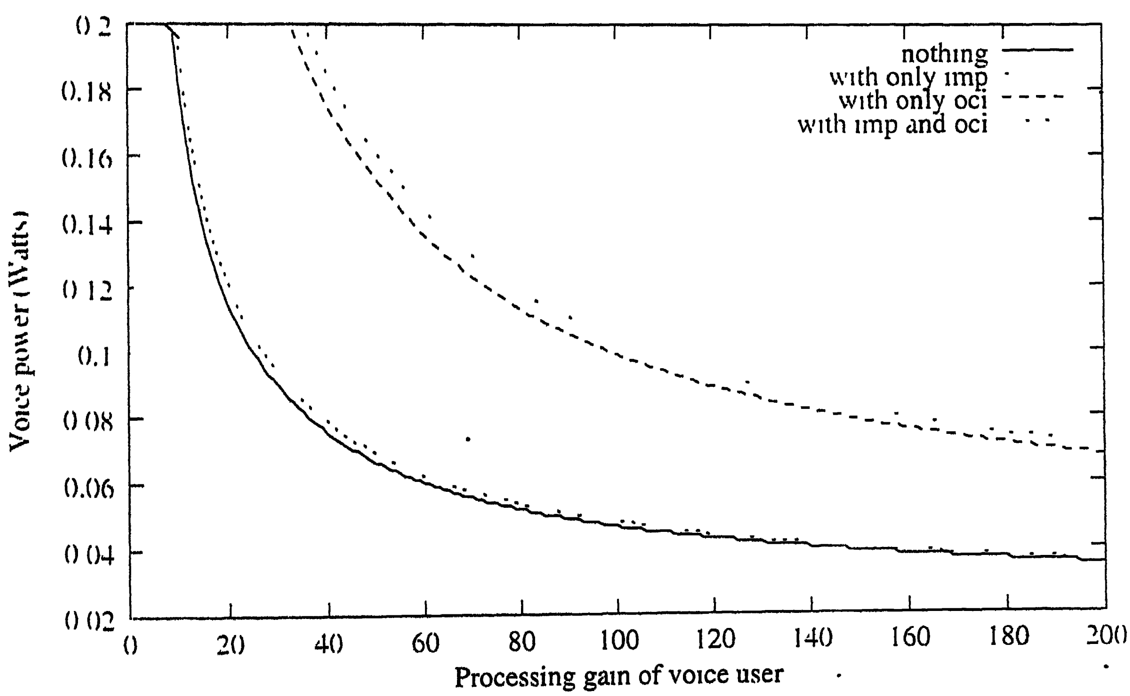

Figure 4.6: Voice power for random voice and random data for Kd=6 and Kv=6 with λ_d=80 packets/s and λ_v=18.75 packets/s in uplink

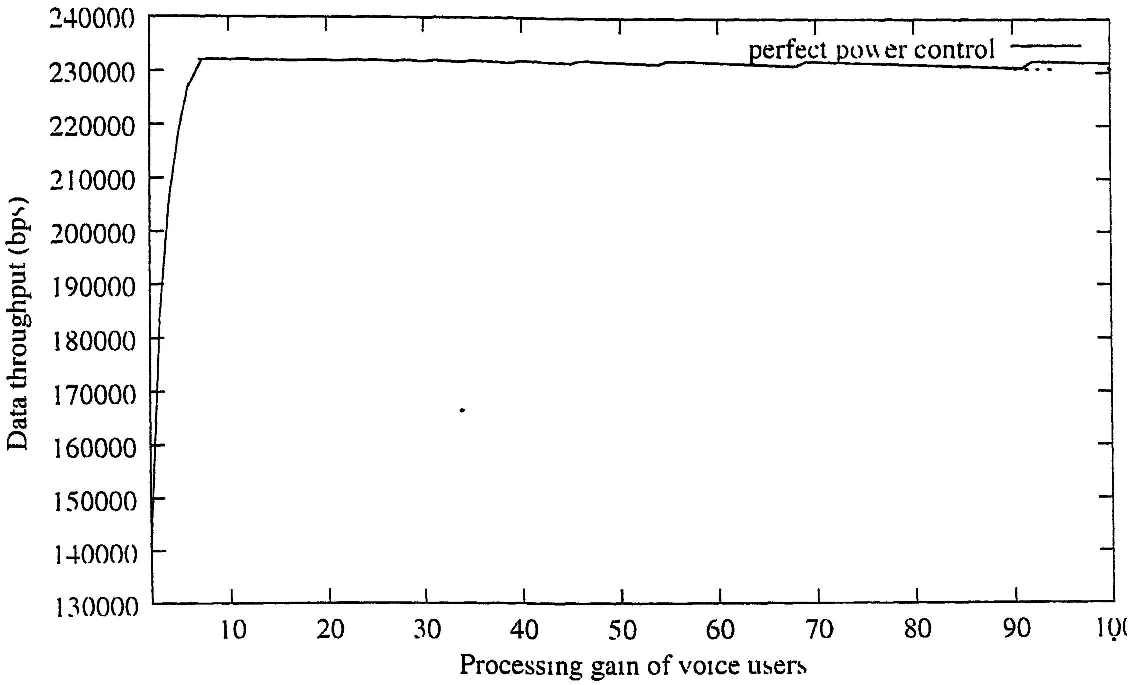

Figure 4.7 Data throughput for random voice and continuous data for Kd=10 and Kv=10 with λ_v=18.75 packets/s in downlink

4.3 Downlink

In downlink algorithm is applied for only perfect power control case. Interference is from the other cell base stations Here algorithm is applied considering 3 tier of cells and reference cell is at origin

4.3.1 Random Voice and Continuously Active Data Users

For the random voice and continuously active data users case Figure 4.7 corresponds to maximum data throughput, Figure 4.8 for optimal data power and Figure 4.9 for optimal voice power. As shown in Figure 4.7 similar to uplink data throughput first increases sharply then decreases slowly

4.3.2 Random Voice and Random Data Users

For the random voice and random data users case, Figure 4.10 corresponds to maximum data throughput, and Figure 4.11 for optimal voice power.

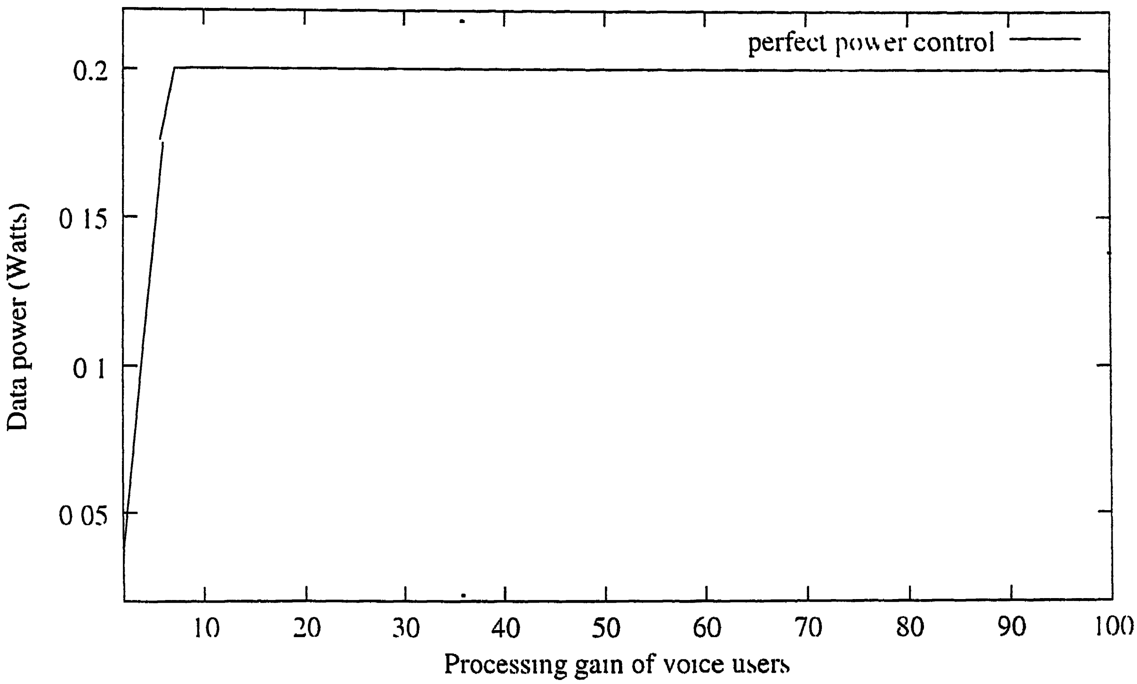

Figure 4.8 Data power for random voice and continuous data for Kd=10 and Kv=10 with λ_v=18.75 packets/s in downlink

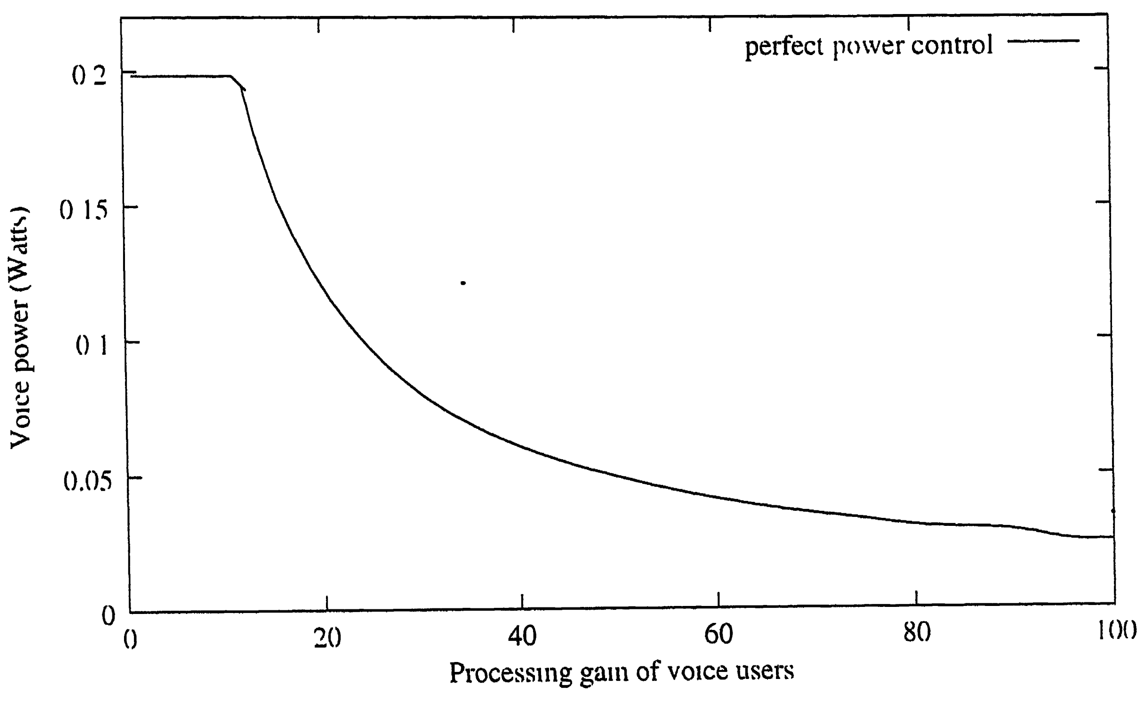

Figure 4.9 Voice power for random voice and continuous data for Kd=10 and Kv=10 with λ_v=18.75 packets/s in downlink

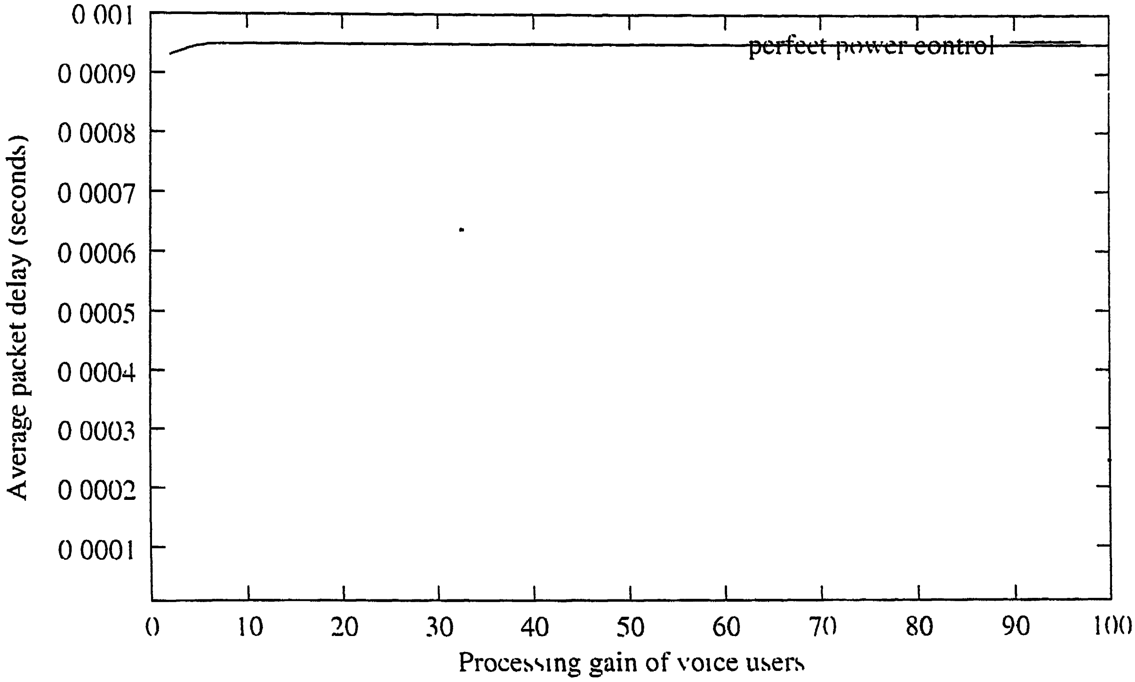

Figure 4 10 Average data packet delay for random voice and random data for Kd=10 and Kv=10 with λ_d=200 packets/s and λ_v=18 75 packets/s in downlink

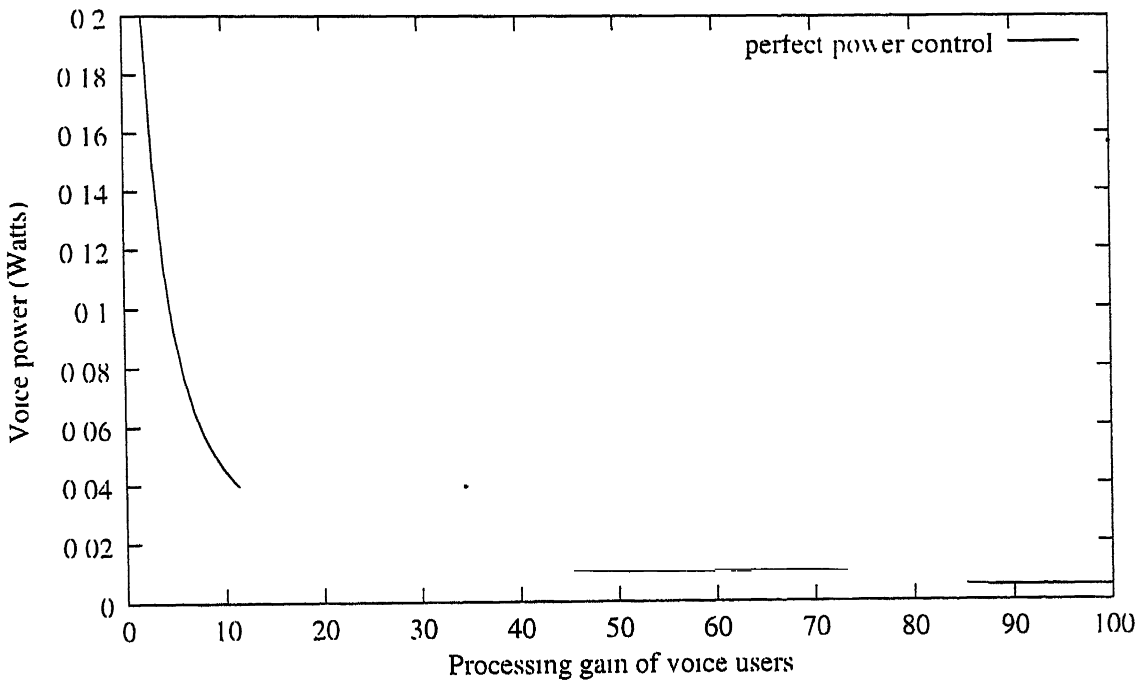

Figure 4 11 Voice power for random voice and random data for Kd=10 and Kv=10 with λ_d=200 packets/s and λ_v=18 75 packets/s in downlink

4.4 Conclusion

Model for a Multi-rate/Multi-QoS packet data DS-CDMA system is analyzed in this thesis The symbol rate is determined by the selection of PG and QoS is determined by both PG and power. Results presented in this thesis show optimal data throughput and power of data and voice users corresponding to different values of voice PG for both uplink and downlink For both continuously active and random active data traffic models we have characterized average delay and throughput for the data users as a function of PG and error probability parameters. For continuously active case data throughput is a more sensitive function of PG. For randomly active users, small PGs can give infinite delay As expected our results indicate that othercell interference and/or imperfect power control reduces the throughput.

4.5 Scope for Future work

In this work we have not considered assigning multiple codes to different classes to achieve multiple transmission rates Other possibilities for future work include consideration of more than two classes of users, channel impairment such as fading, and more sophisticated (multiuser) detection schemes

Appendix A

This appendix has been adopted from [13] We will now derive the approximation in (3 13). Consider

$$p_{b_v} = \int Q(\frac{x}{\sigma_N}) f_X(x) dx = E\left[Q(\frac{X_v}{\sigma_N})\right] \quad (A\,1)$$

where f_X is the probability density function of the interference and power control statistics In other words, the random variable X is distributed with the underlying density function being f_X, and let us denote its mean and variance, $E[X]$ and Var(X) respectively We will obtain an approximation for p_{b_v} in terms of just the mean and variance of X as follows

Let θ be a random variable with mean μ and variance σ^2 Then assuming existence of derivatives, we can rewrite a function P(θ) using Taylor series as follows

$$P(\theta) = P(\mu) + (\theta - \mu)P'(\mu) + \frac{1}{2}(\theta - \mu)^2 P''(\mu) + \ \ldots \quad (A\,2)$$

By truncating the series to just terms of the second order, and taking expectation one gets

$$E[P(\theta)] = P(\mu) + \frac{1}{2}P''(\mu)\sigma^2 \quad (A\,3)$$

If instead of using Taylor series, one uses an expansion in central differences (Stirling formula) [13], then we arrive at the approximation

$$E[P(\theta)] \approx P(\mu) + \frac{1}{2}\frac{P(\mu + h) - 2P(\mu) + P(\mu - h)}{h^2}\sigma^2 \quad (A\,4)$$

for small h The value of h for which above equation holds with equality depends strongly on σ, the standard deviation of θ It was given in [13] that h=$\sqrt{3}\sigma$ makes the approximation for the fifth degree polynomials and normally distributed θ. It was shown that

the above approximation is fairly robust to non-Gaussian distributions and deviations from the above assumptions Using the above approximation on (1) results in

$$p_{b_v} \approx \frac{2}{3}Q\left[\frac{E(X_v)}{\sigma_N}\right] + \frac{1}{6}Q\left[\frac{E(X_v) + \sqrt{3Var(X_v)}}{\sigma_N}\right] + \frac{1}{6}Q\left[\frac{E(X_v) - \sqrt{3Var(X_v)}}{\sigma_N}\right] \quad (A\ 5)$$

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